EVALUATING THE HOOKING INJURY AND IMMEDIATE PHYSIOLOGICAL RESPONSE OF WILD RAINBOW TROUT TO CAPTURE BY CATCH-AND-RELEASE ANGLING

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A

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By

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Abstract

Rainbow trout from the Alagnak River watershed, Alaska, were captured by angling to determine the types of terminal gear contributing to hooking injury and the physiological response to angling based on concerns over high incidences of hooking injuries and the physiological impact of multiple recaptures on individual fish. Landing and hook removal times were recorded for a portion of fish captured, and plasma cortisol, glucose, ions (sodium, chloride, potassium), and lactate were evaluated in fish following capture to document physiological changes in relation to capture duration. The majority of new injuries resulted when fish were captured using barbed J hooks, and barbed J hooks took longer to remove than barbless hooks. Fish were hooked internally more frequently when captured with J hooks compared to circle hooks, but similar overall hooking injury rates were observed for both hook types. Novice anglers injured proportionally more fish than experienced anglers, and experienced anglers took longer to land fish than novice anglers. Plasma cortisol and lactate increased significantly with increasing landing and handling times. Fish captured at cooler water temperatures had significantly lower cortisol and lactate concentrations than fish caught at warmer temperatures indicating that water temperature influenced the magnitude of the physiological response.

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Introduction

Recent studies have emphasized the importance of a holistic approach to evaluating the effects of catch-and-release angling on fish, by evaluating the potentially lethal effects such as hooking mortality, and sublethal effects such as disruptions in feeding behavior resulting from physiological disturbance (Cooke et al. 2002; Stockwell et al. 2002). The results from many studies on the effects of hooking injury on mortality indicate the anatomical hooking location with associated bleeding to be the most important factor influencing initial mortality of angler caught fish (e.g., Falk et al. 1974; Warner 1976; Loftus et al. 1988; Nuhfer and Alexander 1992). Non-lethally injured fish may have a foraging disadvantage due to an eye or jaw injury, and may require more time for recovery than uninjured fish. Increased energy expenditures are required to maintain position in the forage hierarchy by captured and potentially injured fish, leaving less energy available for growth (Lewynsky and Bjornn 1986). Angling is one of the most physically demanding forms of exercise in fish (Booth et al. 1995), and recovery from the physiological disturbance in response to capture by angling may influence feeding behavior (Pickering 1990, Gregory and Wood 1999), migratory behavior (Mäkinen et al. 2000; Thorstad et al. 2003) disease resistance (Pickering and Pottinger 1989; Pickering et al. 1989), and reproductive function (Carragher et al. 1989; Campbell et al. 1992; Cooke et al. 2000; Cooke et al. 2002) of released fish. Physiological disruptions from stress events are cumulative (Barton et al. 1986; Barton 2002); therefore, fish subjected to intense angling pressure that may be caught and released several times during a fishing season may be more vulnerable to these types of effects, and carry a greater chance of being lethally injured.

Fisheries managers and scientists evaluating the sublethal effects from catch-and-release angling and associated hooking injuries on wild fish populations are challenged because of the difficult logistics associated with conducting fieldwork in remote locations in Alaska, and the uncertainty in relating the results from similar studies in controlled environments to the response by wild fish in their natural environment. Studies examining the physiological response or hooking mortality of angled wild fish typically hold fish after capture for observation and repeat sampling, which can potentially bias study results by the addition of confinement and crowding stress (Wright 1972; Pankhurst and Dedual 1994), and further injury from confinement (McLaughlin et al. 1997; Cooke and Hogle 2000). Additional challenges lie in choosing the appropriate measurable effects of angling stress on fish, accounting for unobserved delayed mortality, and interpreting results based on individual fish to population-level effects.

A study of rainbow trout (*Oncorhynchus mykiss*) from the Alagnak River in 1997-1998 revealed over 30% of trout caught in the watershed to have at least one distinctive scar most likely resulting from previous hooking (J. M. Meka, unpublished data). The Alagnak Wild River, a conservation unit partially within Katmai National Park and Preserve in southwest Alaska, supports natural, self-reproducing populations of rainbow trout and is one of the most heavily used trout sport fisheries in southwest Alaska. Visitor use for sport fishing on the Alagnak has increased greatly since the early 1980's, prompting emergency catch-and-release fishing regulations to be adopted in 1996, and made permanent in 1998 (Meka et al. 2003). Numerous cases of angler dissatisfaction due to Alagnak River rainbow trout deformities or scars purportedly resulting from repeated hooking, as well as complaints of a decrease in fish size and abundance, have been reported by anglers (Meka et al. 2003; J. Meka, personal observation). The detrimental aesthetics of injured trout have reduced the overall appreciation of the Alagnak River by many anglers, who occupy the majority of visitor use of the watershed. It is desirable to evaluate any lethal effects from catch-and-release angling caused by hooking injuries or physiological disruptions associated with angling, without holding fish after capture for observation to avoid stress and injury resulting from confinement, because there are existing concerns about the health of the rainbow trout population in response to the dramatic increase in angling pressure (Cooke and Hogle 2000; Meka et al. 2003). Therefore, research on the various factors that influence hooking injury and the duration of the angling process including landing and handling during the hook removal process, without the necessity of holding fish after capture, may provide supplemental information essential in evaluating ways to reduce angling mortality and sublethal effects of Alagnak River rainbow trout (Wright 1972).

Chapter 1: Hook type and angler experience influence injury rates and the duration of capture in an Alaskan catch-and-release rainbow trout fishery[1]

Abstract

Fish subjected to catch-and-release sport fisheries may be subject to multiple recaptures, increasing the chances of individual fish experiencing lethal and non-lethal hooking injuries. Due to concerns over high incidences of past hooking injuries in Alagnak River rainbow trout, fish were captured using fly and spin fishing gear with barbed and barbless circle and "J" hooks to determine the types of gear contributing to injury. Landing and hook removal times were measured for a portion of fish captured, and the anatomical hooking location, hooking scar locations, bleeding intensity, angler experience, and fish size were recorded for all captured fish. Angler experience was classified as novice (fished < 10 days over lifetime) and experienced (fished > 10 days per year). Immediate mortality was observed in eight fish (1.2%; 8/666), the majority of which were hooked internally and experienced moderate to heavy bleeding. Approximately 58% (386/666) of fish captured experienced at least one new hooking injury and 30% (196/666) of fish captured had at least one past hooking injury. The majority of new injuries resulted when fish were captured using barbed J hooks (67%; 217/325) and barbed J hooks took longer to remove than barbless hooks. Fish were hooked internally more frequently when captured by fly fishing with J hooks compared to

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circle hooks, but similar overall hooking injury rates were observed in fish caught by J (57%; 173/306) or circle hooks (46%; 31/67). Capture efficiency was greatest when fish were caught using barbed J hooks. Novice anglers injured proportionally more fish (70%; 51/73) than experienced anglers (56%; 334/592), but experienced anglers took longer to land fish than novice anglers. These results suggest the potential benefits of reducing hooking injury and time to remove hooks by a barbed J hook restriction, and the importance of angler education to reduce landing time and promote proper hook removal techniques.

Introduction

Recent studies have emphasized the importance of a holistic approach to evaluating the effects of catch-and-release angling on fish, by evaluating sublethal effects, such as decreased growth or fecundity, as well as lethal effects (Cooke et al. 2002; Stockwell et al. 2002). Additional sublethal effects that may not cause immediate mortality in fish subjected to angling stress, but may influence the survival of individual fish may include physiological disruptions from landing time, handling time, and exposure to air during the hook removal process or when being photographed, and the potentially confounding effects of non-lethal hooking injuries. Physiological disruptions from stress events are considered cumulative (Barton et al. 1986); therefore, fish subjected to intense angling pressure that may be caught and released several times during a fishing season may be more vulnerable to disease, parasites, and predators (Snieszko 1974; Esch et al. 1975;

Wydoski 1977), and carry a greater chance of being lethally injured. Fisheries managers and scientists face challenges when attempting to evaluate these effects on wild fish populations because of the logistics of conducting fieldwork in remote locations in some areas, the feasibility and associated effects of holding fish after capture for observation, the possibility of unobserved delayed mortality, and the uncertainty in relating the results from research conducted in hatcheries or laboratories to the equivalent response in wild fish. Further challenges lie in choosing the appropriate measurable effects of angling stress on fish, in addition to immediate mortality, and interpreting the results monitored in individual fish to population level effects.

Non-lethally injured fish may be at risk to opportunistic organisms, disease, or fungal infection, and certain injuries may influence the feeding habits or survival of fish (Wright 1972; Chipeniuk 1997). Numerous studies on the effects of hooking injuries on mortality indicate the anatomical hooking location with associated bleeding to be the most important factor influencing initial mortality of angler-caught fish (e.g., Falk et al. 1974; Warner 1976; Loftus et al. 1988; Nuhfer and Alexander 1992). Many studies have had variable results on whether the use of barbed hooks influences fish injury and mortality (Falk et al. 1974; Dotson 1982; Mongillo 1984; Barnhart 1990; Muoneke and Childress 1994), however, the degree of damage and handling time during the hook removal process is generally higher in fish captured using barbed hooks than on barbless hooks (Muoneke and Childress 1994; Cooke et al. 2001). A few recent studies have focused on the impacts of angler experience on the duration of the angling process and associated hooking injuries (Dunmall et al. 2001), and whether the use of circle hooks in freshwater fisheries could serve as a conservation tool by reducing the severity of hooking injuries (Cook et al. 2003 b, c); however, these effects have not been evaluated for wild rainbow trout.

A study of rainbow trout (*Oncorhynchus mykiss*) from the Alagnak River in 1997-1998 revealed over 30% of trout caught in the watershed to have at least one distinctive scar most likely resulting from previous hooking (J. M. Meka, unpublished data). The Alagnak Wild River, a conservation unit partially within Katmai National Park and Preserve in southwest Alaska, supports natural, self-reproducing populations of rainbow trout and is one of the most heavily used trout sport fisheries in southwest Alaska. Visitor use for sport fishing on the Alagnak has increased greatly since the early 1980's, prompting emergency catch-and-release fishing regulations to be adopted in 1996, and made permanent in 1998 (Meka et al. 2003). Numerous cases of angler dissatisfaction due to Alagnak rainbow trout deformities or scars purportedly resulting from repeated hooking by anglers have been reported, as well as complaints of a decline in rainbow trout abundance and size (Meka et al. 2003; J. Meka, personal observation). The detrimental aesthetics of injured trout may have reduced the overall appreciation of the Alagnak River by many anglers, who occupy the majority of visitor use of the watershed. Research on the angling factors that influence hooking injuries and the duration of capture may provide supplemental information essential in evaluating ways to reduce angling mortality (Wright 1972) and sublethal effects, by recognizing methods that reduce the severity of injury and handling time.

The primary objective of this study was to examine the rates of present hooking injuries in Alagnak River rainbow trout captured using fly and spin fishing techniques with barbed and barbless J hooks and circle hooks. A second objective was to compare the differences in landing time, handling time, and frequency of injury between novice and experienced anglers to determine whether angler experience influences hooking injury and the duration of capture. One unique aspect of this study was to assess immediate hooking injury without holding fish after capture for observation, which can bias hooking mortality estimates by the confounding stress effects from confinement and associated handling that may decrease the survival potential and fish condition of confined fish after release (Wright 1970; Cooke and Hogle 2000).

Methods

Field study – Rainbow trout were captured by hook and line in the Alagnak River watershed at Nonvianuk Lake outlet and the main stem Alagnak River between June 10 and August 8, 2000, and June 8 and August 19, 2001. From June 8-24, 2002, fish were caught by hook and line at the outlets of both Nonvianuk and Kukaklek lakes (Figure 1.1). Most of the fishing effort took place in the braided reaches of the Alagnak River main stem and lake outlets, where the majority of the trout sport fishery is concentrated. While fishing on the main stem river, the daily decision of where to fish depended mainly on where the fishing was most successful the previous day reflecting common strategies used by anglers and guides in this area.

Anglers consisted of fisheries biologists and technicians with the United States Geological Survey (USGS) and National Park Service, Student Conservation Association (SCA) volunteers, and other governmental and non-governmental volunteers. Angler experience varied greatly, from novice (first time fishing) to experienced anglers, who typically fished over 100 days a year in both river and lake systems. Each angler completed a survey designed to categorize anglers into a specific level of expertise. Categories included novice (fished < 10 times over their lifetime), and experienced (fished > 10 days per year). Novice anglers were given informal fishing lessons, and instructed in proper handling and hook removal techniques prior to fishing.

Both fly and spin fishing methods were used to capture fish to reflect typical angling conditions for rainbow trout on the Alagnak River. The decision to test the difference in the hooking injury effects between J hooks and circle hooks was based on the theory that circle hooks cause less injury because the points are bent inward towards the hook shank, a design in which fish are less likely to become deeply hooked (Montrey 1999; Cooke et al. 2003 *a*). Barbed and barbless J hooks were tested for both spin and fly fishing, and barbed and barbless circle hooks were used for fly fishing only. Hooks were made barbless by crimping the barb down on circle and J hooks. Size 8 J hooks were used for fly and spin fishing, size 8 circle hooks (Eagle Claw, model NT2050) were used in 2000 and 2001, and size 6 circle hooks (Gamakatsu Octopus Circle, model 20841) were used in 2002. The sizes of hooks were determined by measuring the hook against a hook-gap measuring gage because sizes can vary slightly among hook manufacturers. The six methods of fishing were divided into the following categories: 1) spin barbed J hook; 2) spin barbless J hook; 3) fly barbed J hook; 4) fly barbless J hook; 5) fly barbed circle hook; and 6) fly barbless circle hook. Anglers were assigned a method of fishing twice daily determined by uniform randomizing of the methods at the beginning of the fishing season each year of the study. Lures and flies were chosen based on the advice of local guides and anglers, and anglers participating in this study chose their own lures and flies each day per assigned fishing method.

The times (minutes and seconds) to land fish and handle fish while removing the hook were recorded for a portion of fish captured. In general, fish were landed when they could be netted without difficulty and were never played to exhaustion. Anglers were advised to land fish as they normally would while fishing recreationally, thus the time it took to land fish varied for each angler. Landing time started when a fish was initially hooked until the fish was netted, generally close to shore, by another angler. Once a fish was netted, the landing time stopped and the handling time during the hook removal process began. The handling time stopped when the angler removed the hook. Anglers were advised to keep the fish under water during the entire hook removal process to avoid potential mortality due to air exposure (Bouck and Ball 1966; Ferguson and Tufts 1992).

Start and stop times for each element of a capture, the method of fishing (fly or spin), and hook type (barbed or barbless, J or circle), and lure or fly type were recorded. Once a fish was netted, the anatomical hooking location was recorded and the angler who caught the fish removed the hook. The anatomical hooking location was assigned to a specific category: jaw, eye, deep (gills, tongue, esophagus, roof of mouth), or other (i.e., head, nose, gular region, fins, tail), and also grouped into one of two categories for data analysis. These were defined as internal (including eye, esophagus, gills, tongue, roof of mouth) and external (foul, operculum, gular region, upper and lower jaw, snout), (modified from Loftus et al. 1988). The eye was included in the internal category because it has been demonstrated that fish hooked in the eye, esophagus, gills, and tongue suffer the highest mortality rates (Stringer 1967; Hunsacker et al. 1970; Warner 1979; Siewert and Cave 1990). Once the hook was removed, fish were examined for any bleeding from the hook wound or flowing from the gills. Bleeding intensity was recorded as either present (Cooke et al. 2003 *b*) or absent. Fish were measured for fork length (mm) and weight (g), and the mouth was thoroughly examined for any past or present injuries thought to be due to capture by angling. Any other scars or abnormalities on each fish were also recorded. Past hooking scars were defined as healed wounds obviously due to previous injury from angling, and present wounds were defined as those that occurred during the angling and hook removal process by anglers participating in this study that would likely result in scarring. Present or past hooking scars were separated into the same anatomical location categories as the initial hooking location (i.e., jaw, eye, deep, other). Fish were released near the area of capture. Fish hooked, but not landed (further described as "lost"), were defined as those that were initially hooked, but escaped during the landing process. If a fish was lost, the fishing method (fly or spin, J or circle hook, barbed or barbless) and angler were recorded. Catch efficiency was defined as the ratio of the number of fish lost to the total number of fish lost and landed per gear type, method of fishing, or level of angler experience.

Prior to the opening of the fishing season in June 2001, the Nonvianuk Lake outlet was seined to obtain an estimate of past hooking injuries on rainbow trout not captured by hook and line in this study. After fish were removed from the net, they were placed into sampling tubs filled with freshwater and the fork length (mm), weight (g), and past hooking injuries were recorded. These data were used to compare the incidence of past injuries with fish caught by hook and line at the lake outlet.

Statistics and data analysis.—Logistic regression analysis (SAS software version 8.00, SAS Institute, Inc.) was used to determine which variables significantly influenced the frequency of hooking injuries or bleeding including method of fishing using J hooks (fly or spin), barbed or barbless hooks (fly or spin, J or circle for fly fishing), J or circle hooks (fly fishing only), angler experience, and fish size. The influences of the method of fishing, barbed or barbless hooks, J or circle hook, angler experience, and fish length on initial anatomical hook location or hook removal time were evaluated independently using logistic regression or one-way analysis of variance (ANOVA, Minitab software version 13, Minitab Inc.). The influence of angler experience and fish length on landing time was evaluated using ANOVA. The time to land fish was log-transformed to correct for non-normality of the data. Fish length for logistic regression and ANOVA analysis was used as a continuous variable, and also divided into two categories (small <440 mm and large >440 mm), with the division based on large fish being the most sought after trout in the sport fishery. Logistic regression was used to determine if fish size indicated a tendency for the presence or absence of past and present hooking injuries using the small and large fish size categories.

Chi-square contingency tables (Everitt 1977, Minitab software version 13, Minitab Inc.) were used to compare the relationship between the proportion of injured fish and angler experience, method of fishing, and hook type (barbed and barbless, J and circle hook), and the proportion of fish with past injuries caught angling or by seine. Chi-square contingency tables were used to determine whether the numbers of fish caught and lost were independent of fly and spin fishing, barbed and barbless hooks, and J and circle hooks. All statistical tests were considered significant at $P \leq 0.05$. All three years of data were combined for analysis because methods remained constant throughout the study.

Results

A total of 666 rainbow trout (mean FL [± SE] = 352.25 ± 7.60 mm) were captured by angling. Three hundred and six fish were caught fly fishing with J hooks, 293 were caught spin fishing with J hooks, and 67 were caught fly fishing with circle hooks (Table 1.1). The majority of fish captured using J hooks were hooked by at least one hook point in the upper jaw (49%), with the lower jaw (22%), eye (10%), and deep (7%, esophagus, tongue, gills) the next most common hooking locations (Figure 1.2). Fish captured using circle hooks were hooked most commonly in the upper jaw (67%), with the lower jaw (16%) the next most common hooking location. Hook points penetrated more than one anatomical location in approximately 10% (n = 68) of rainbow trout, with hooks most commonly penetrating both the jaw and eye (44%, n = 30), and the upper and lower jaw (25%, n = 17). Of these fish, 98% (n = 67) were captured using J hooks and 2% (n = 1) were captured using circle hooks.

The method of fishing (fly or spin with J hooks) and barbed or barbless J hooks were not related to the initial anatomical hooking location categories of jaw, eye, deep or other, and internal or external ($P > 0.05$). The majority of hooking locations were in the upper and lower jaw, however, a significantly greater percentage of fly fishing-caught fish were hooked internally with J hooks than with circle hooks ($P = 0.0105$; 97%, n = 116, and 3%, n = 3, respectively). Small fish were hooked internally more frequently than large fish, regardless of hook type (small fish < 440mm FL: 88%, n = 102; large fish > 440 mm: 12%, n = 14; $P = 0.0139$). Immediate mortality was observed for eight fish (1.2%), the majority of which were small (< 440 mm), hooked internally in the tongue or gills (87%, n = 7), and experienced blood flow from the wounds.

Fifty-eight percent (n = 386) of fish caught during this study were given at least one new hooking injury that would most likely result in scarring from torn tissue. The majority of injuries were in the upper or lower jaw (74%), with the eye (11%), and injuries within the other (8%) and deep (esophagus, gills, tongue; 8%) categories the next most common injury locations. There was no significant difference in the proportion of newly injured fish caught with J hooks by fly fishing (57%, n = 173/306) compared to spin fishing (62%, n = 182/293; $P = 0.165$; Table 1.1), or fish injured while fly fishing with circle hooks (46%, n = 31/67) compared to J hooks (56%, n = 173/306; $P = 0.1277$;

Table 1.1). For fly fishing only, more fish were lost using circle hooks (48%, n = 62/129) than were lost using J hooks (36%, n=172/478) ($X^2 = 6.256$, df = 1, P = 0.012; Table 1.1), and unrelated to the circle hook being barbed or barbless ($X^2 = 2.864$, df = 1, P = 0.091). Of fish injured using fly and spin fishing gear with J hooks (n = 355), more fish were injured using barbed hooks (67%, n = 217/325) than barbless hooks (50%, n = 138/274; P < 0.0001; Table 1.1). Barbed J hooks were more efficient at landing fish than barbless hooks, with fewer fish lost using barbed J hooks (37%, n=192/517) than were lost using barbless hooks (50%, n = 270/544; $X^2 = 16.835$, df = 1, P = 0.001; Table 1.1), regardless of fly or spin fishing. Based on the number of fish caught fly and spin fishing with J and circle hooks by novice or experienced anglers, novice anglers injured proportionally more fish than experienced anglers (novice 70%, n = 51/73; experienced 56%, n = 334/592; P = 0.0299; Table 1.1). The use of two sizes of circle hooks during the study did not have any effect on the frequency of injury (P = 0.3766) or catch efficiency ($X^2 = 0.065$, df = 1, P = 0.799).

Bleeding from new hooking injuries occurred in 25% (n = 167/666) of fish captured. Fish hooked internally bled more frequently than fish hooked externally (58% and 22%, respectively; P = 0.0001). There was no difference in the frequency of bleeding between J and circle hooks (P = 0.0819). Based on logistic regression analysis of all fish caught by fly (n = 373) and spin (n = 293) fishing, bleeding was more significant in fish caught spin fishing (P = 0.0150) using barbed hooks (P = 0.0407).

At least one past hooking injury was present in 29% (n = 195/666) of fish captured during the study, 38% (n = 75/195) of which had more than one past hooking scar. The majority of past hooking scars were located on the upper or lower jaw (82%, n = 160/195), with scars in the other category (11%, n = 22/195) and eye (4%, n = 8/195) the next most common locations. Logistic regression and chi-square test analysis were used to determine if fish size indicated a tendency for the presence or absence of past and present hooking injuries using the small (< 440 mm) and large (> 440 mm) fish size categories. Approximately 53% (n = 73/137) of large fish had at least one past hooking injury, while 23% (n = 123/529) of small fish had at least one past hooking injury ($P < 0.0001$), indicating that larger fish were more likely to have a previous injury. These results differed from fish with new hooking injuries, with approximately 44% (n = 60/137) of large fish given at least one new hooking injury, and 62% (n = 326/529) of small fish given at least one new hooking injury ($P = 0.0002$), indicating that smaller fish were more likely to receive a new injury during capture. The frequency of past injuries in seined fish (24%, n = 24/100) was not significantly different from angler-caught fish ($X^2 = 0.314$, df = 1, $P = 0.575$; 28%, n = 20/72). Fish with past injuries were similar in length regardless of capture method, with the average length of fish with past injuries greater than the length without injuries (no past injury, mean FL [± S.E.] seine: 323.9 ± 12.34 mm, angle: 348 ± 19.58 mm, $P = 0.684$; past injury, seine: 415.7 ± 34.32 mm, angle: 416.4 ± 29.52 mm, $P = 0.774$).

To determine whether the amount of time it took to land fish was related to fish size, regression analysis was used with the log of landing time as the dependent variable, and length (FL mm) as the independent variable (n = 371). Large fish took longer to land than small fish ($P = 0.001$). Analysis of variance was used to observe any difference in the amount of time to land fish with (n = 112/371) or without (n = 259/371) previous hooking injuries. Fish with past hooking injuries took longer to land than fish without injuries (mean ± S.E., no past injury: 1:29 ± 0:8, with past injury: 1:56 ± 0:20; P = 0.001). Because fish with past hooking injuries were larger than fish without past hooking injuries, the time to land fish was positively correlated with both fish size and presence of past hooking injuries. When analyzed separately, there was no significant difference in landing time between small fish with and without past injuries (P = 0.551) and large fish with and without past injuries (P = 0.560). Experienced anglers took significantly longer to land fish than novice anglers (Figure 1.3). Thus, it can be assumed that fish size and angler experience are most likely the strongest factors influencing landing time. The amount of time required to remove hooks was not related to angler experience, fishing method, fish size, or between J and circle hooks (P > 0.161). However, hook removal time was significantly longer when barbed J hooks were used compared to barbless J hooks (Figure 1.3). This relationship was not significant between barbed or barbless circle hooks (P = 0.323).

Discussion

Barbed J hooks caused significantly more new hooking injuries, took longer to remove, and were more efficient at catching fish than barbless hooks in this study. The greater frequency of injury and longer handling times were most likely due to the difficulty in hook removal and barbed hooks becoming tangled in the landing nets, both of which I observed to intensify hooking injuries and incidence of bleeding. Similar results were observed from Klamath River steelhead (anadromous rainbow trout) caught by barbed and barbless flies, and a barbless-hook-only regulation was recommended to reduce handling time and mortality by ease of hook removal, and to potentially decrease the number of fish landed (Barnhart 1990). Taylor and White (1992) concluded that the mortality rates for fish caught using artificial flies, lures, and bait with barbed hooks were higher than in fish caught with barbless hooks. These results prompted barbed hook restrictions in several freshwater fisheries in the United States (Schill and Scarpella 1997; Turek and Brett 1997). Barbless hooks have been shown to cause a lower incidence of damage and bleeding than barbed hooks, as well as decreased the amount of time fish were handled and exposed to air while removing hooks (Muoneke and Childress 1994; Cooke et al. 2001). Schill and Scarpella (1997) view the issue of the differences in hooking mortality in freshwater trout caught by barbed or barbless hooks to be purely social and lacking biological significance because little difference has been reported in the mortality rates between fish caught with barbed or barbless hooks in numerous past studies. However, direct mortality may not be the only important factor to consider because recovery from injury and blood loss following a stress event, such as capture by angling, may interfere with the natural feeding, reproduction, physiology, behavior, and disease resistance of angled fish (Snieszko 1974; Lewynsky and Bjornn 1987; Campbell et al. 1992; Schreck et al. 1997), all of which are considered to be of biological significance and play central roles in survival.

Although circle hooks had a significantly lower catch efficiency rate than J hooks, fish caught with circle hooks were hooked internally less than fish caught with J hooks, but overall injury rates were similar (circle 46%, J hook 56%). From my own observations, circle hooks were more difficult to remove than J hooks and caused more tissue damage in external locations. This observation was also noted by Cooke et al. (2003 *b*), who reported that more tissue damage resulted when removing circle hooks from largemouth bass (*Micropterus salmoides*), even when the hook removal procedure was classified as "easy". The design of circle hooks may be more efficient at hooking rainbow trout in the jaw and with only one hook penetration per capture, yet the low catch efficiency and overall injury rate similar to standard J hooks may make them less desirable to anglers than is being promoted by the popular literature. The use of circle hooks in marine fisheries has been gaining credence as causing less hooking damage and mortality in the scientific as well as popular literature (e.g., Prince et al. 2002; Skomal et al. 2002), with suggestions that the hook type may provide similar benefits in freshwater fisheries (Strange 1999). However, little research has been done to compare hooking injury and catch efficiency of circle hooks to standard hooks with freshwater fish species, particularly trout. Cooke et al. (2003 *a*, *b*) observed circle hooks to be less efficient at hooking largemouth bass and rock bass (*Ambloplites rupestris*) than conventional hook types. However, injury and frequency of bleeding were less with circle hooks, making them a potentially suitable conservation tool by minimizing angling mortality. The use of circle hooks to catch bluegill (*Lepomis macrochirus*) and pumpkinseed (*Lepomis gibbosus*) resulted in less gullet hooking but greater eye hooking rates compared to conventional hooks, which has been shown to cause significant mortality in bluegill (Siewart and Cave 1990; Cooke et al. 2003 *c*). A recent study observed greater catch efficiency of rainbow trout and brown trout (*Salmo trutta*) captured with circle hooks compared with J hooks, and a lower frequency of internal injuries than was observed in my study (Pecora, D., Connecticut Department of Environmental Protection, unpublished data). The variability in the results of these studies may be in part due to differences in terminal tackle used (e.g., bait or artificial flies), but also the foraging behavior and mouth morphology of the specific species of study (Cooke et al. 2003 *c*).

The overall incidence of bleeding in captured fish was relatively low in my study (25%), but most significant in fish hooked internally. Fish hooked in critical areas such as the esophagus, eye, gill region, or tongue have the highest initial mortality rates (Stringer 1967; Hunsacker et al. 1970; Warner 1979; Loftus et al. 1988). Approximately 19% of fish caught during this study were injured in critical areas, with 8% injured in the esophagus, gills, or tongue, and 11% given eye injuries. Bleeding associated with being hooked internally can also contribute greatly to mortality, because injuries to critical internal areas bleed more than external locations (Falk et al. 1974; Nuhfer and Alexander 1992; Schisler and Bergersen 1996). Some studies have reported over 40% mortality in salmonids hooked in the eye, and 25 - 71% mortality when hooked in the esophagus, gills, or tongue (Warner 1976; Mongillo 1984; Loftus et al. 1988). I observed immediate mortality in only eight fish (1.2%), seven of which were hooked internally and experienced blood flow from the wound. The majority of mortality from angling occurs within the first 24 - 48 hours following capture, but fish with less severe hooking wounds may take up to 10 days to die (Mongillo 1984). Based on inference gained from the studies mentioned above on the range of mortality estimates of salmonids hooked in critical areas, the potential mortality rate of fish hooked in critical areas in this study could have ranged from 8 to 11%, which includes the observed eight mortalities.

Permanent scarring from hooking injuries is inevitable in fish that survive being caught-and-released or are initially hooked but not landed, even in a fishery with low angling mortality. The most common new hooking injuries, as demonstrated in this study, were to the jaw region (e.g., missing maxillary, inverted maxillary, scarring to the dentary) and eye. Few studies have given attention to the biological significance of scarring, such as growth effects and loss of tissue, the origin of hooking injuries rather than their influence to mortality, or the aesthetic importance of scars to the angling public. There are several important factors to consider on the issue of scarring from a hooking injury. First, injuries may expose fish to opportunistic organisms, disease, or fungal infections. It has been suggested that injury to the eyes from hooking or confinement in largemouth bass puts the cornea at risk of infection by opportunistic organisms (McLaughlin et al. 1997), and injuries to smallmouth bass (*Micropterus dolomieu*) from retention gear used for confinement led to delayed fungal infections and sometimes death (Cooke and Hogle 2000). Parasitic copepods of the genus *Salmincola,* most likely *S. californiensis* (Conley and Curtis 1993; T. Burton, Alaska Department of Fish and Game), were found at the base of the fins, attached to gill filaments, or inside the mouth in 58% of Alagnak River rainbow trout during this study. Anecdotally, I observed rainbow trout with past hooking injuries to have higher incidences of

Salmincola than fish without injuries. In fish subjected to different types of stress such as capture by angling or recovery from injury, the natural resistance of the fish to parasites may be reduced, which can increase the density of parasite populations (Esch et al. 1975).

Second, certain non-lethal hooking injuries may influence the feeding habits or survival of fish (Wright 1972). For example, based on mark-recapture estimates for chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon injured by sport fishing gear, Wright (1972) estimated a 4 - 36% mortality rate in fish injured to the extent where vision or feeding ability were compromised. Fish permanently injured in the eye region may lose the ability to forage competitively and avoid predators (Cooke et al. 2003 *c*). A feeding cessation by fish in response to stress, such as handling, crowding, or angling, has been reported to last from hours to days in the literature (Pickering et al. 1982; Schreck et al. 1997; D. Beyers, Colorado State University, unpublished data), sometimes resulting in growth reduction (Clapp and Clark 1989). In areas where food is limited, catch-and-release fishing may have a negative impact on fish growth and overall health (Stockwell et al. 2002). Fish subjected to multiple captures per season may be more vulnerable to reduced growth (Clapp and Clark 1989), particularly if the effects of each capture are cumulative (Barton et al. 1986).

Third, the presence of hooking scars greatly diminishes the aesthetic value of wild fish, which attracts worldwide anglers to fish Alaska waters relatively uninfluenced by humans compared to areas in the continental United States. Fishing has virtually become a "socially acceptable source of anthropogenic stress" (D. Beyers, Colorado State

University, Department of Fishery and Wildlife Biology, personal communication), yet the permanent non-lethal injuries on fish subjected to catch-and-release fishing and subsequent biological or social consequences from these injuries have been given little to no attention by fisheries scientists, managers, and the general public.

Novice anglers often had difficulty removing both J and circle hooks, and consequently injured proportionally more fish than experienced anglers. Dunmall et al. (2001) reported that experienced anglers influenced the initial hooking location and severity of hooking injuries in smallmouth bass compared to novice anglers, but did not necessarily influence the time to remove the hook. Large fish (> 440 mm; FL) in this study took significantly longer to land, and angler experience also played a role in the duration of landing time during this study, with experienced anglers taking significantly longer to land fish than novice anglers. The duration of landing time has been demonstrated to cause significant physiological disruptions in wild rainbow trout, yet has generally resulted in little to no observed mortality (Wydoski et al. 1976; Pankhurst and Dedual 1994). Because no fish during this study were angled to exhaustion, and landing times were primarily less than 2 minutes, it is unlikely that much mortality resulted from the duration of landing time. However, sublethal effects such as changes in reproductive behavior (Carragher et al. 1989, Campbell et al. 1992, Cooke et al. 2000), disease resistance (Pickering and Pottinger 1989), growth suppression or decrease in appetite (Pickering 1990, Gregory and Wood 1999), and other behavioral effects (Lewynsky and Bjornn 1987, Heath 1990, Gregory and Wood 1998, Thorstad et al. 2003) have resulted from various types of stress. Particularly in sport fisheries where fish may be caught several times within a fishing season, it is important to reduce the amount of time fish are landed, handled, and exposed to air during the angling process to avoid potential mortality or sublethal effects.

I demonstrated that valuable information on the factors influencing the severity of hooking injuries in wild rainbow trout can be obtained without holding fish after capture, because the mortality rates of rainbow trout hooked in certain locations have been extensively researched and inference can be drawn to estimate mortality based on the location of observed hooking wounds. The results of my study indicate that there are potential benefits of certain fisheries regulations to minimize hooking injuries in wild rainbow trout subjected to a catch-and-release fishery. For example, a restriction on barbed J hooks would reduce the frequency of hooking injuries and associated bleeding rates, and reduce the amount of time fish are handled when removing hooks. As the popularity of angling for wild rainbow trout continues to rise in Alaska, resulting in heavier angling pressure, voluntary and mandated catch-and-release angling practices will inevitably continue to increase. Managers will need to carefully consider the impacts of multiple recaptures on the aesthetic value of wild fish to visiting anglers and focus future research on the prolonged effects of hooking injury on trout populations.

If the management goal would be to limit the amount of rainbow trout caught and released, a restriction to circle hooks only should aid in reducing lethal hooking injuries and make the actual hooking and landing of fish more challenging and possibly self-limiting. However, if circle hooks for use on freshwater fish continue to increase in popularity and new and more efficient hooks become available, an increase in catch efficiency may result in increased injuries. Although these results apply most specifically to the Alagnak River rainbow trout fishery, they are representative of other popular, non-consumptive rainbow trout fisheries in Alaska. By minimizing the risk and degree of injury, and initiating angler education programs to include the importance of a short duration of capture, proper removal of hooks, and conservation-minded release techniques, fish survival may be maximized and the aesthetic value of wild fish could be more effectively preserved.

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	Total fish hooked	Caught	# Injured	% Injured	Fish lost	
					Number	Percent
FLY FISHING						
Barbed J (total)	275	187	114	0.61	88	0.32
Barbless J (total)	203	119	59	0.50	84	0.41
Total	478	306	173	0.57	172	0.36
SPIN FISHING						
Barbed J (total)	242	138	103	0.75	104	0.43
Barbless J (total)	341	155	79	0.51	186	0.55
Total	583	293	182	0.62	290	0.50
FLY AND SPIN FISHING						
Barbed J (total)	517	325	217	0.67	192	0.37
Barbless J (total)	544	274	138	0.50	270	0.50
Total	1061	599	355	0.59	462	0.44
FLY FISHING						
Barbed Circle (total)	62	37	17	0.46	25	0.40
Barbless Circle (total)	67	30	14	0.47	37	0.55
Total	129	67	31	0.46	62	0.48
ANGLER EXPERIENCE						
Novice		73	51	0.70		
Experienced		592	334	0.56		
Total		665	385	0.58		
OVERALL TOTAL	1190	666	386	0.58	524	0.44

Table 1.1. Number of Alagnak River rainbow trout caught by angling or lost (hooked but not landed) during the reeling in process during June-August 2000-2002. Fish were captured using six types of gear: fly fishing with barbed or barbless "J" hooks, spin fishing with barbed or barbless "J" hooks, and fly fishing with barbed or barbless "circle" hooks. Novice anglers were defined as individuals who fished less than 10 days over their lifetime, and experienced anglers fished greater than 10 days per year.

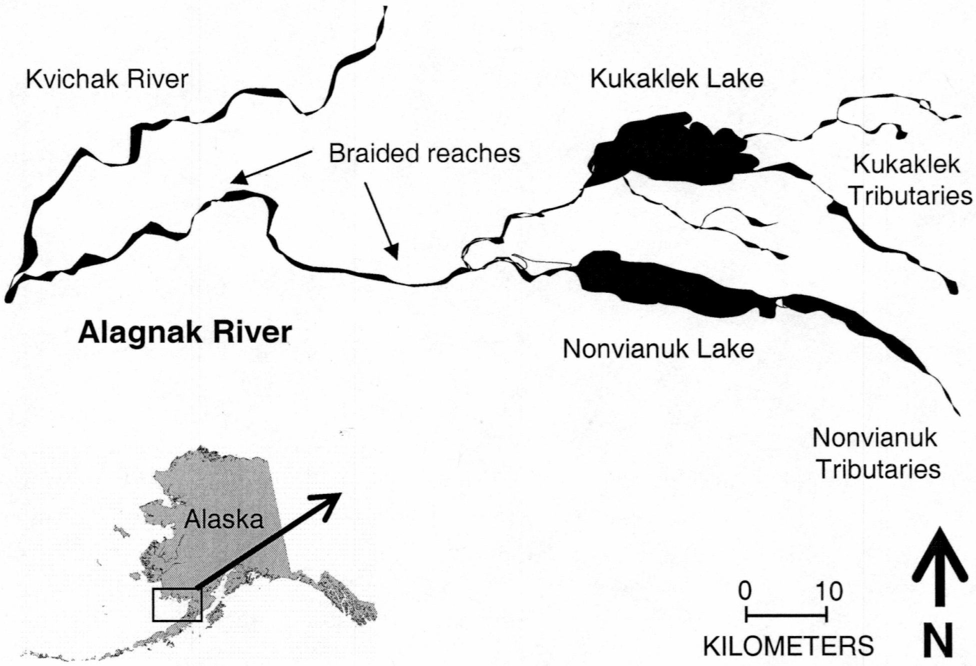

Figure 1.1. Map of the Alagnak River watershed in southwest Alaska. Rainbow trout were captured by hook and line on the Alagnak River main stem and at the outlets of Kukaklek and Nonvianuk lakes.

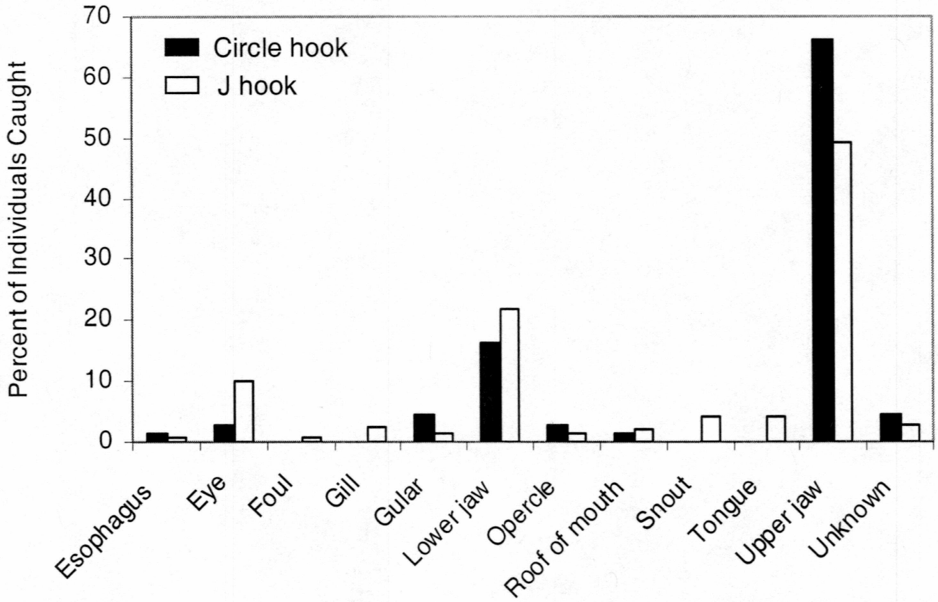

Figure 1.2. Percentage of rainbow trout hooked in different anatomical locations with at least one hook point penetration using standard J hooks and circle hooks. Fish were included in the "unknown" category if the hooks were released before the angler began the hook removal process and there was no obvious sign of the hooking location or wound from the hook site.

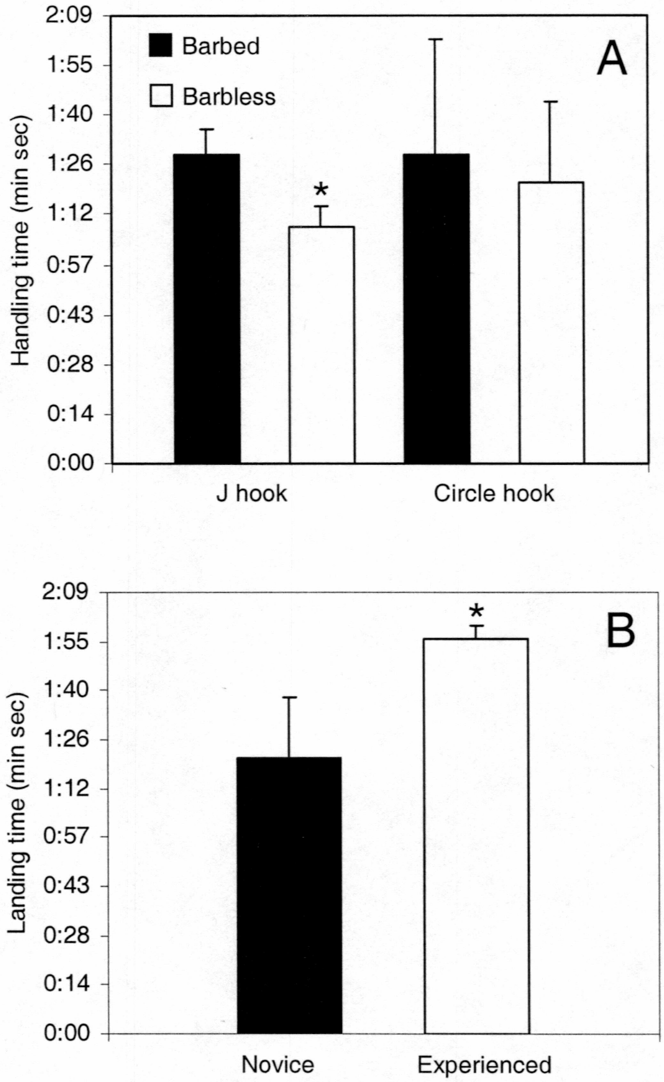

Figure 1.3. Differences in hook removal time by hook type and landing times by angler experience. A) The hook removal time (mean + S.E.) for fish captured using barbed (n=197) and barbless (n=202) J hooks while fly and spin fishing, and barbed (n=24) and barbless (n=17) circle hooks while fly fishing. Statistically significant differences (P<0.05) between hook types is noted by an asterisk. B) The landing time (mean + S.E.) for fish captured by novice (n=41) and experienced (n=399) anglers using barbed and barbless J and circle hooks while fly and spin fishing. Statistically significant differences (P<0.05) between landing times is noted by an asterisk.

Chapter 2: Evaluating the physiological response of angled wild rainbow trout to the duration of capture, handling time, and temperature [1]

Abstract

This study evaluated the immediate physiological response of wild rainbow trout in the Alagnak River, southwest Alaska, to the duration of capture by catch-and-release angling and handling during the hook removal process, and in relation to water temperature. Information was recorded on individual rainbow trout (n=415) captured by angling including the duration of capture and the time required to remove hooks and handle fish during that process, the time to anesthetize fish in clove oil and withdraw blood, fish length, and water temperature at capture locations. Plasma cortisol, glucose, ions (sodium, potassium, chloride), and lactate were analyzed to determine the effects of the duration of the landing process, handling time, and water temperature. Levels of cortisol and lactate were evaluated in fish angled and handled in less than 2 minutes (rapid capture) and greater than 2 minutes (extended capture). The levels of plasma cortisol and lactate increased significantly as the combined duration of landing time and the time fish were handled during the hook removal process increased. Levels of cortisol and lactate were significantly elevated in fish angled and handled for 2-5, depending on the year. Rapid capture fish were significantly smaller than extended capture fish, reflecting that fish size influenced landing and handling times. Water temperatures were

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[1] Prepared for submission to *Fisheries Research.* Meka, J.M., McCormick, S.D., Evaluating the physiological response of angled wild rainbow trout to the duration of capture, handling time, and temperature. Fisheries Research.

higher in 2001 (mean temperature ± SE, 13 ± 2°C) than in 2002 (10 ± 2 °C), and fish captured in 2001 had significantly higher cortisol and lactate concentrations than fish caught in 2002, indicating that water temperature, additional to angling stress, had influence on the range of the physiological response. Levels of plasma glucose and ions did not change significantly during the observed physiological response. The results of this study indicate the importance of landing fish quickly and using hooks that are easy to remove, in order to reduce the physiological response by wild fish subjected to catch-and-release capture, particularly during warmer water temperatures.

Keywords: Oncorhynchus mykiss, catch-and-release fishing, stress physiology, water temperature, cortisol, lactate

Introduction

Wild fish caught by catch-and-release angling are subjected to physical exhaustion during the landing process, lethal and non-lethal hooking injuries, and handling and air exposure during the hook removal process. In addition to studies focusing on the relationship between hooking injury and mortality (e.g., Muoneke and Childress 1994), many studies indicate the importance of physiological distress during the angling process as contributing to short-term mortality (Wydoski et al. 1976, Dotson 1982, Titus and Vanicek 1988, Barrett and McKeown 1989, Lee and Bergersen 1996). In general, studies documenting the physiological disturbance of wild fish from hooking stress have found minimal mortality (Wydoski et al. 1976, Gustaveson et al. 1991, Tufts et al. 1991, Pankhurst and Dedual 1994, Booth et al. 1995, Brobbel et al. 1996, Thorstad et al. 2003), however mortality may increase when fish are angled at warmer water temperatures (Wilkie et al. 1996). There are also sub-lethal effects that may be induced by physiological changes provoked by a stress event including changes in reproductive behavior or function (Carragher et al. 1989, Campbell et al. 1992, Cooke et al. 2000, Cooke et al. 2002), disease resistance (Pickering and Pottinger 1989, Pickering et al. 1989), growth suppression or decrease in appetite (Pickering 1990, Gregory and Wood 1999), and other behavioral effects such as changes in social hierarchies and migratory behavior (Lewynsky and Bjornn 1987, Heath 1990, Gregory and Wood 1999, Mäkinen et al. 2000, Thorstad et al. 2003). Physiological disruptions from stress events are considered cumulative (Barton et al. 1986); therefore, fish that may be caught and released several times during a fishing season may be more vulnerable to these types of sub-lethal effects.

Increases in levels of plasma cortisol from the release of corticosteroids after the onset of an acute stress, as well as secondary physiological responses such as hyperglycemia, hyperlacticemia, and ionic disturbance, have been measured to assess the effects of landing time (Wydoski et al. 1976, Gustaveson et al. 1991, Pankhurst and Dedual 1994, Thorstad et al. 2003). Recent studies have also addressed the effect of hook type on the ease of removal by comparing various hook types, such as circle versus standard "J" hooks and barbed versus barbless hooks (Cooke et al. 2001, Cooke et al. 2003 *a*, *b*, *c*), and by measuring the physiological response to air exposure, which commonly occurs during the hook removal process (Ferguson and Tufts 1992, Cooke et al. 2001, Thorstad et al. 2003). Studies examining the physiological response or hooking mortality of angled wild fish typically hold fish after capture, which can potentially bias study results by the addition of confinement and crowding stress (Wright 1972, Pankhurst and Dedual 1994), and further injury from confinement (McLaughlin et al. 1997, Cooke and Hogle 2000). While it is recognized that the most comprehensive type of study to evaluate the effects of catch-and-release fishing in wild fish includes monitoring the behavior and recovery of angled fish after release (Cooke et al. 2002), the associated injuries and potential addition of confinement stress make holding fish after capture undesirable for some fish populations.

An extensive amount of research has been conducted to evaluate the magnitude and duration of the physiological response of rainbow trout to exhaustive exercise in hatchery environments (e.g., Wood et al. 1983, Woodward and Strange 1987, Pickering and Pottinger 1989, Barton and Iwama 1991, Pankhurst and Dedual 1994, Davidson et al. 2000). However, little *in situ* research has been completed on the physiological response of wild rainbow trout to angling in their natural environment. The Alagnak Wild River, a conservation unit partially within the Katmai National Park and Preserve of the National Park Service in southwest Alaska, supports a naturally reproducing population of wild rainbow trout (<u>Oncorhynchus mykiss</u>) which are targeted by a popular catch-and-release only sport fishery. Catch-and-release only regulations were made permanent due to concerns over the health of rainbow trout population subjected to intense angling pressure during a 3-4 month angling season, with reports from local guides and anglers of high incidences of hooking scars and decreasing fish size and abundance (Meka et al. 2003, Meka, personal observation). Approximately 30% of Alagnak River rainbow trout have at least one scar purportedly due to previous hooking, indicating that a substantial portion of the population is subjected to multiple angling captures (Meka, unpublished data). The objectives of this study were to evaluate the initial stress response in Alagnak River rainbow trout in relation to landing time and handling time during the hook removal process, fish size, and fluctuating seasonal water temperatures, by measuring concentrations of plasma cortisol, glucose, lactate, and ions for fish with combined landing and handling times of less than 2 minutes (rapid capture) and greater than 2 minutes (extended capture) (adapted from Pankhurst and Dedual 1994). Results on the initial physiological stress response exhibited by angled rainbow trout will be compared with results from previous investigations on the magnitude and duration of the stress response, without the necessity of holding fish after capture.

Materials and Methods

Adult rainbow trout were captured by hook-and-line in July and August 2000, and June-August 2001 in the Alagnak River main stem and at Nonvianuk Lake outlet within Katmai National Park and Preserve (Figure 2.1). Fish were caught at the outlets of Kukaklek and Nonvianuk lakes in June 2002. Anglers participating in this study included United States Geological Survey (USGS) biologists, Katmai National Park and Preserve biologists, Student Conservation Association volunteers, and volunteers from the general public and other government agencies. The times to land fish and remove hooks were recorded. Handling time (hook removal) began when a fish was netted after landing until the angler removed the hook, and anglers were instructed to keep fish under water during the handling portion of capture to avoid any associated mortality due to air exposure (Bouck and Ball 1966, Ferguson and Tufts 1992). Anglers were instructed to land fish as they normally would while fishing recreationally, but not to play fish to exhaustion. However, in 2002 anglers were instructed to play some fish for more than one minute while continuing to avoid exhausting fish, to obtain a broader range of sampling times.

Once the hooks were removed, fish were anesthetized in a rectangular container close to the area of capture with 25 l of fresh river water and a concentration of 32 mg/l solution of clove oil (1:9 ratio clove oil mixed with ethanol; Anderson et al. 1997). Blood was withdrawn from the caudal vessels using heparinized syringes with 21 or 22 gage needles. Plasma was separated immediately and stored in liquid nitrogen tanks in the field, and subsequently at -80^{o}C in the lab until further analysis. In addition to landing and hook removal times, the times to anesthetize fish, to withdraw blood, and the total sampling time (from initial hooking until blood sampling was completed) were recorded. Fish were placed in another rectangular container with fresh river water to recover after blood was withdrawn. Fork length (mm) and water temperature (^{o}C) near the area of capture were recorded. Fish were released near the area of capture following recovery.

The influences of landing time and of the time to remove hooks to physiological parameters were combined because both exhaustive exercise and handling stress have been shown to cause physiological changes in rainbow trout, and it was not feasible to separate their effects in this study (Sumpter et al. 1986, Pickering and Pottinger 1989, Wood 1991, Ferguson and Tufts 1992). The amount of time fish were anesthetized in clove oil and sampled for blood under anesthesia was not included in analysis of the elevation of blood parameters because it has been shown that the physiological response to fish in clove oil is minimal, and accurately reflects stress prior to anesthesia (Davidson et al. 2000, Wagner et al. 2002). Thus, landing time and the time required to remove hooks were considered to be the most influential to any physiological changes, due to the physically exhaustive nature of both stressors (Wood et al. 1983, Ferguson and Tufts 1992, Booth et al. 1995). Fish were separated into rapid and extended capture groups because it has been demonstrated that physiological changes can occur within a few minutes after the onset of a stressor, therefore, the levels of blood parameters for rapid capture fish would potentially reflect the levels of normally active fish (Wydoski et al. 1976, Gustaveson et al. 1991, Pankhurst and Dedual 1994).

Plasma cortisol, glucose, ions (2000 only), and lactate were analyzed at the USGS Conte Anadromous Fish Research Center (Turners Falls, MA, USA). Plasma cortisol was measured by a fully validated direct enzyme immunoassay (EIA) as outlined in Carey and McCormick (1998). Glucose was evaluated by the hexokinase and glucose-6-phosphate dehydrogenase enzymatic method (Stein 1963, McCormick and Björnsson 1994). Plasma lactate concentrations were determined by reduction of nicotinamide adenine dinucleotide with lactate deydrogenase as described by Marbach and Weil 1967 (Carey and McCormick 1998). Plasma cortisol, glucose, and lactate assays were run using SOFTmax software and THERMOmax microplate reader (Molecular Devices, Menlo Park, CA, USA). Chloride, potassium, and sodium concentrations were determined by ion-selective electrodes (AVL Scientific Corp., model 9180, Roswell, GA, USA) using appropriate standards (McCormick and Björnsson 1994).

Multiple regressions with stepwise selection were conducted to determine the effects of combined landing and handling times, water temperature, fish length, and sampling year on concentrations of plasma cortisol, glucose, ions, and lactate. If significance was observed in relation to time or temperature, one-way analysis of variance (ANOVA) was used to determine whether there were significant changes over time (by minute of combined landing and handling times) and water temperature (by ^{o}C) in extended capture fish, and to detect differences among years in water temperature. If significant differences were detected by ANOVA, data were analyzed by a Tukey-Kramer multiple comparisons test to compare mean plasma concentrations per minute of combined landing and hook removal time in extended capture fish to the concentrations in rapid capture fish, or per degree water temperature of extended capture fish. Any influence of fish size on the combined landing time and hook removal time was evaluated by simple linear regression, and the lengths of fish within the rapid and extended capture groups were compared by a Tukey-Kramer multiple comparisons test. When necessary, landing time data were log transformed to correct for non-normality of the data. All statistical tests were conducted using SAS software (SAS Institute, Version 8) at the $P < 0.05$ significance level.

Results

Levels of plasma glucose concentrations in 2000-2002 (mean mmol/l ± SE, 4.4 ± 0.12, n = 415), and plasma sodium (151.8 ± 2.5, n = 55), potassium (3.29 ± 0.18 mmol/l, n = 52) and chloride (138.8 ± 2.0 mmol/l, n = 55) in 2000, did not vary significantly in relation to landing and handling times, water temperature, or fish length. There was a year-effect observed in plasma cortisol and lactate, thus each year of data was analyzed separately. The combined influence of increasing landing time and the time required to remove hooks produced a significant increase in levels of plasma cortisol and lactate during each year of the study ($P < 0.003$). The average levels of cortisol and lactate for rapid capture fish were significantly lower than levels in extended capture fish ($P < 0.0092$, Figure 2.2). The average landing and handling time for fish captured in 2000 and 2001 (mean ± SE, 2:58 ± 0:09) was less than in 2002 (4:10 ± 0:27) because anglers were instructed to play fish for longer amounts of time without exhausting fish.

Fish length was significantly related to cortisol levels in 2001 ($P < 0.0001$), with cortisol levels increasing with fish size. Although fish length was not related to increases in plasma cortisol in other years or lactate during any year ($P > 0.05$), fish length was significantly correlated to the combined landing and hook removal times during all years of the study ($P < 0.0001$). The average fork length (mm) of rapid capture fish was significantly smaller than the average length of extended capture fish ($P < 0.05$, Table 2.1), i.e., larger fish took longer to land and handle than smaller fish. The amount of time to anesthetize fish in clove oil did not vary significantly between rapid capture (mean ±

SE, 2:13 ± 0:11) and extended capture (2:07 ± 0:08) groups of fish ($P = 0.510$), indicating that fish size did not significantly influence anesthetization times and most likely did not have a strong influence on the elevation of cortisol and lactate.

Water temperature varied significantly among years (mean temperature ± SE; 2000 = 12 ± 1°C; 2001 = 13 ± 2°C; 2002 = 10 ± 2°C; $P < 0.05$), and increases in plasma cortisol (2001) and plasma lactate (2001, 2002) were significantly related to water temperature ($P < 0.0001$). Temperatures in 2001 were generally higher than in 2002, and levels of plasma cortisol and lactate in rapid and extended capture fish in 2001 were significantly higher than corresponding levels in 2002 ($P < 0.05$, Figure 2.2b). Plasma cortisol and lactate concentrations increased with the amount of time fish were angled regardless of the temperature range; however, the magnitude and range of the response was higher in 2000-2001 when the temperatures were warmer (Figure 2.3).

Discussion

The levels of plasma cortisol for rapid capture fish identified in this study were within the range of resting or baseline levels previously reported for rainbow trout (Woodward and Strange 1987, Pickering and Pottinger 1989, Barton and Iwama 1991, Pankhurst and Dedual 1994, Davidson et al. 2000). However, levels of plasma lactate for rapid capture fish were much higher than resting levels (landed in <5 minutes) reported for wild rainbow trout by Pankhurst and Dedual (1994) and baseline levels in hatchery trout which were determined by terminally sampling fish at rest (Milligan and Girard

1993). One of the greatest challenges to effectively monitor the physiological response of wild fish to capture stress is the ability to establish baseline values of blood chemistry (Wydoski et al. 1976). It is possible that levels of plasma lactate observed in this study began to increase over resting levels immediately after hooking rainbow trout, and true baseline levels were not observed in rapid capture fish. Physically conditioned rainbow trout have been shown to have higher lactate concentrations than unconditioned fish (Love 1970), indicating that perhaps the high lactate levels observed in Alagnak River rainbow trout reflected their physical condition. No significant changes in plasma glucose and ions were observed in this study, rather the levels of glucose and ions were within the baseline range previously reported in the literature (Wedemeyer et al. 1990, Barton et al. 2002). Typically, a net loss of sodium and chloride ions is observed following exhaustive exercise or stress in salmonids, but usually takes hours to manifest (Brobbel et al. 1996, Carey and McCormick 1998). In a comparison between hatchery and wild rainbow trout subjected to 1-5 minutes of hooking stress, Wydoski et al. (1976) found no significant changes in plasma osmolality reflected in changes to ionic components in wild fish. Plasma glucose has been observed to increase significantly 5 minutes after the onset of hooking stress in rainbow trout, particularly for fish acclimated to higher temperatures (12° C and 20° C) (Wydoski et al. 1976). However, in numerous controlled studies on the effect of stressors, it has been observed to take up to an hour to see significant increases in plasma glucose (Ristori and Laurent 1985, Barton and Dwyer 1997, Carey and McCormick 1998). The absence of significant increases in plasma glucose and ions is likely due to the relatively short time frame within which samples were taken in the present study, thus there may have been a delayed response between the baseline glucose and ion response I observed and the potential manifestation of the response at a later time (Barton et al. 2002), perhaps influenced by cooler water temperatures (Barton and Schreck 1987). Life history or genetic differences, as well as the fish's environment, may also be a source of variation in blood chemistry among salmonid stocks (Barton et al. 1986, Barton et al. 2002).

Alagnak River rainbow trout exhibited increases in plasma cortisol and lactate concentrations relative to the amount of time fish were angled and handled during the hook removal process. Capture by angling is one of the most physically demanding forms of exercise stress in fish (Booth et al. 1995) and the subsequent physiological response has been demonstrated to increase with the amount of time fish are on the hook (Wydoski et al. 1976, Gustaveson et al. 1991, Pankhurst and Dedual 1994, Thorstad et al. 2003), sometimes resulting in high mortality rates (Bouck and Ball 1966). Handling stress has also been demonstrated to cause significant physiological disruptions (Sumpter et al. 1986, Pickering and Pottinger 1989, Ferguson and Tufts 1992, Barry et al. 1996), and handling stress during the hook removal process is a concern among researchers examining the response of fish to catch-and-release angling (Cooke et al. 2001, Thorstad et al. 2003). In previous studies where the relationship between capture by angling and the subsequent physiological response was examined, fish were typically anesthetized in a tricaine methanesulfonate (MS222) solution before blood sampling, and the time in anesthesia and for blood withdraw were generally not factored into the analysis (Wydoski et al. 1976, Gustaveson et al. 1991, Booth et al. 1995, Brobbel et al. 1996). The physiological stress response of fish anesthetized in MS222 or clove oil solution has ranged from minimal to significant, largely depending on the duration of time fish are in the anesthetic, the specific anesthetic and dose, when the dose was delivered, and the species of study (Barton and Peter 1982, Barton and Iwama 1991, Tort et al. 2002, Wagner et al. 2002). It has been demonstrated in adult rainbow trout that exposure to AQUI-S™ (clove oil solution) similar to the dose and induction time used in this study (2-3 minutes per individual fish) resulted in a minimal increase in plasma cortisol and the stress response was likely caused by initial crowding during transport to anesthesia baths (Wagner et al. 2002). Davidson et al. (2000) found that rainbow trout subjected to crowding stress following 30 minutes of exposure to AQUI-S™ had a similar plasma cortisol response as fish subjected to crowding without anesthesia, indicating that the use of clove oil did not block the cortisol response or cause a significantly greater disturbance. It should be recognized that some of the variation observed in physiological parameters measured when fish are under anesthesia following a stress event may be partially due to differences in anesthetization times, which can contribute to sampling times and ultimately physiological changes. However, the use of clove oil in this study most likely did not suppress the stress response in rainbow trout, but rather measured the continuing response to the duration of landing and hook removal times due to the exhaustive nature involved in landing and handling fish, and because induction times were relatively short, averaging slightly over 2 minutes for rapid and extended capture fish.

Fish were not held after capture in this study to avoid the confounding effects of confinement, which may contribute to capture stress and increase the amount of handling associated with repeat sampling, particularly in wild fish (Wright 1972, Woodward and Strange 1987, Gustaveson et al. 1991, Pankhurst and Dedual 1994, Cooke and Hogle 2000). Rather, inference on the duration of the plasma cortisol and lactate responses was drawn from numerous studies that have examined the magnitude of the physiological response and recovery of rainbow trout from physiological distress. Caution is warranted if attempting to repeat a similar method of assessing only the immediate stress response and relating results to similar studies, if there is not a diverse and comprehensive background in the literature on the magnitude and duration of the stress response in the species of study. The initial slope of increase for levels of plasma cortisol and lactate in extended capture Alagnak River rainbow trout following landing and handling stress likely had influence on the peak stress response. It has been demonstrated that the magnitude of the physiological response in fish subjected to various forms of stress largely depends on the severity or duration of the specific stressor (Bouck and Ball 1966, Wydoski et al. 1976, Mazeaud et al. 1977, Ristori and Laurent 1985, Barton et al. 1986, Woodward and Strange 1987, Barton and Iwama 1991, Pickering 1992, Davidson et al. 2000, Grutter and Pankhurst 2000). For example, Pankhurst and Dedual (1994) observed wild rainbow trout captured by angling and played for 5 minutes to have a less severe initial and peak stress response of plasma cortisol and lactate than fish played for more than 15 minutes, yet the recovery period for both groups of fish was similar. Similar results have been observed in wild Atlantic salmon (Salmo salar) (Thorstad et al. 2003) and rainbow trout in a hatchery environment (Pickering and Pottinger 1989, Ferguson and Tufts 1992), yet the recovery rates were longer in fish subjected to less severe types of stress, often determined by the duration of the specific stressor.

In general, the amount of time required for the physiological levels (e.g., plasma cortisol) of salmonids to recover to resting levels from an acute stress event, such as capture by angling or handling and confinement, is within 24 hours (Barton et al. 1986, Pickering and Pottinger 1989, Wood 1991, Pankhurst and Dedual 1994). However, recovery can be longer or shorter depending on the severity of stress and other variables such as the duration of the stressor, fish size, stress from confinement, temperature, developmental stage, and differences between hatchery and wild fish (Wydoski et al. 1976, Woodward and Strange 1987, Pickering and Pottinger 1989, Pankhurst and Dedual 1994, Carey and McCormick 1998). It is difficult to predict the recovery times of fish captured during this study because fish were not held after capture for repeat sampling. However, because fish were not played to exhaustion or exposed to air which can contribute to mortality and increase the physiological stress response (Ferguson and Tufts 1992), it can be assumed that the peak response and recovery of Alagnak River rainbow trout was a reflection of the duration of landing and hook removal times, and typical of past studies where recovery occurs within 24 hours.

Based on the results from this study, rainbow trout with landing and handling times ranging between 2-5 minutes, depending on the year, had significantly higher levels of plasma cortisol and lactate than in rapid capture fish, indicating that the severity of the stress response increased as the duration of sampling time increased. Rainbow trout in the extended capture group presumably experienced a greater peak plasma cortisol and lactate response and longer recovery period than fish captured more quickly. Although the relationship between landing and handling time and physiological disturbance was only significant for cortisol in 2001, landing time significantly increased with fish size and likely indirectly influenced the physiological response during all years of the study. Anecdotally, in a parallel study to the present one, it was demonstrated that the use of barbed J hooks took significantly longer to remove than barbless hooks in Alagnak River rainbow trout, and experienced anglers (fished > 10 days per year) took longer to land fish than novice (fished < 10 days over their lifetime) anglers (Meka, unpublished data). Thus, it is important to educate anglers on the significance of landing fish quickly and of using terminal tackle to reduce handling time after capture, as it will potentially reduce the physiological response and recovery rate of rainbow trout subjected to angling stress.

The average water temperature in this study, as well as levels of plasma lactate in rapid and extended capture fish, was higher in 2001 than in 2002. The pattern of increase in the physiological response was likely due to the amount of time fish were angled, yet the magnitude of the response was also a reflection of the range of water temperatures each year. Fish acclimated to seasonally fluctuating water temperatures may experience equivocal patterns of physiological response to similar types of stress, yet there may be differences in basal and elevated levels depending on the range of temperatures (Barton and Schreck 1987, Barrett and McKeown 1989, Davis and Parker 1990, Kieffer et al. 1994). For example, largemouth bass (Micropterus salmoides) captured by hook-and-line during March, May, and July, when seasonal temperatures increased over time, had basal and elevated levels of blood lactate that reflected the range of water temperatures (Gustaveson et al. 1991). Groups of largemouth bass captured within the three temperature ranges all experienced increases in blood lactate as the duration of hooking time increased, yet fish captured at the warmest temperatures had higher basal and elevated lactate than fish captured at the cooler temperatures. Separating the effects of water temperature and landing and hook removal on the physiological response of Alagnak River rainbow trout is difficult because all have been shown to cause physiological disruptions. Water temperature likely influenced the range of cortisol and lactate levels in this study, and landing and hook removal times influenced the magnitude and rate of elevation of cortisol and lactate (Gustaveson et al. 1991, Cooke et al. 2002).

Although minimal immediate mortality was observed in this study, it is uncertain whether any delayed mortality from angling occurred, or the types of sublethal impacts experienced by individual fish subject to catch-and-release angling. The observed increases in plasma cortisol and lactate may be indicative of stress responses that could have long term sublethal impacts on individual rainbow trout. For example, the cessation of feeding after exposure to acute stress events has been demonstrated in salmonids, sometimes resulting in a reduction of growth (Pickering et al. 1982, McCormick et al. 1998, Mesa and Schreck 1989), presumably through the effect of cortisol (Gregory and Wood 1999). It has been demonstrated that multiple acute stress events caused a cumulative physiological response in fish (Barton et al. 1986), yet the impact on feeding behavior and growth in wild trout subjected to one single angling stress event or multiple captures over a period of a few months has not been investigated to my knowledge.

Minimizing the amount of time fish are landed and handled during the angling process will ultimately reduce the peak physiological response and duration of recovery of angled fish, particularly at warmer water temperatures. Although these results apply most specifically to the Alagnak River rainbow trout fishery, they are representative of other popular non-consumptive rainbow trout fisheries in Alaska. As the popularity of angling for wild rainbow trout continues to rise in Alaska, resulting in heavier angling pressure, voluntary and mandated catch-and-release angling practices will inevitably continue to increase. Managers will need to carefully consider the physiological impacts of multiple recaptures on the response of wild fish and focus future research on the sublethal effects of angling and handling duration on individual rainbow trout, and trout populations.

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	2000				2001				2002			
	Cortisol	N	Lactate	N	Cortisol	N	Lactate	N	Cortisol	N	Lactate	N
Land+handling time (minutes)												
<2 (rapid capture)		10		12		63		61		5		10
2		17		16		96		90		18		21
3		17		17		52		49		32		35
4		16		16		24		23		15		18
5		-		-		17		14		10		9
6		-		-		-		-		12		12
Fish length (mm)												
Rapid capture	305 ± 31	10	295 ± 29	12	325 ± 17	63	321 ± 16	61	327 ± 28	5	317 ± 18	10
Extended capture	392 ± 90*	50	394 ± 25*	49	371 ± 13*	189	371 ± 14*	176	406 ± 18*	87	407 ± 17*	95
Total number of fish sampled		60		61		252		237		92		105

Table 2.1. The sample size (N) and average fork length (mm) of rainbow trout sampled for plasma cortisol and lactate following capture by angling. Rapid capture fish were landed and handled during hook removal for less than 2 minutes, and extended capture fish for greater than 2 minutes. Data are given in means ± SE. Statistically significant differences ($P<0.05$) in fish length between rapid and extended capture fish are indicated by asterisks.

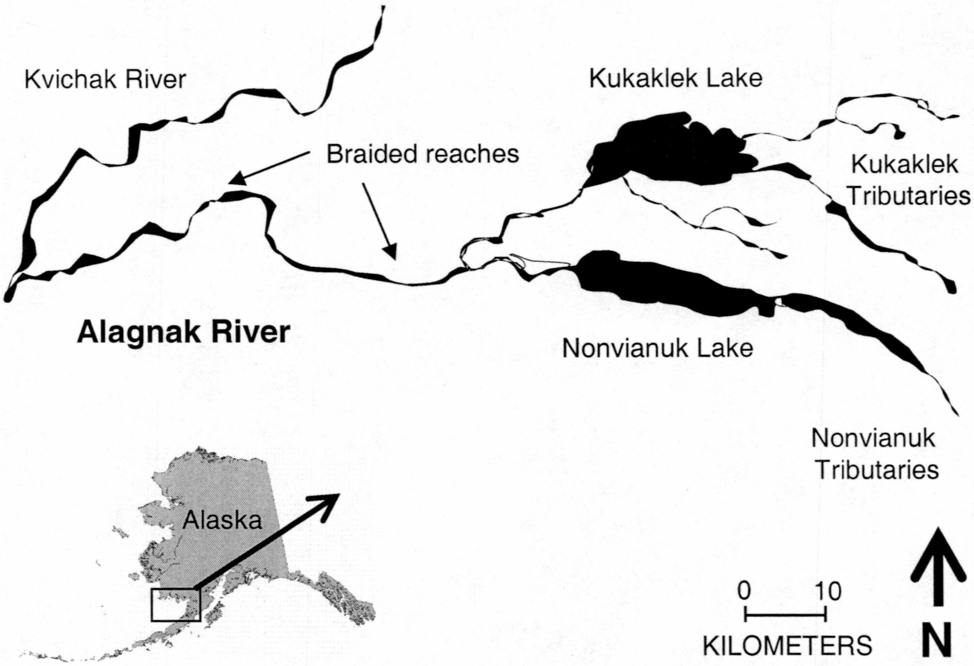

Figure 2.1. Map of the Alagnak River watershed in southwest Alaska. Rainbow trout were captured by hook and line on the Alagnak River main stem and at the outlets of Kukaklek and Nonvianuk lakes.

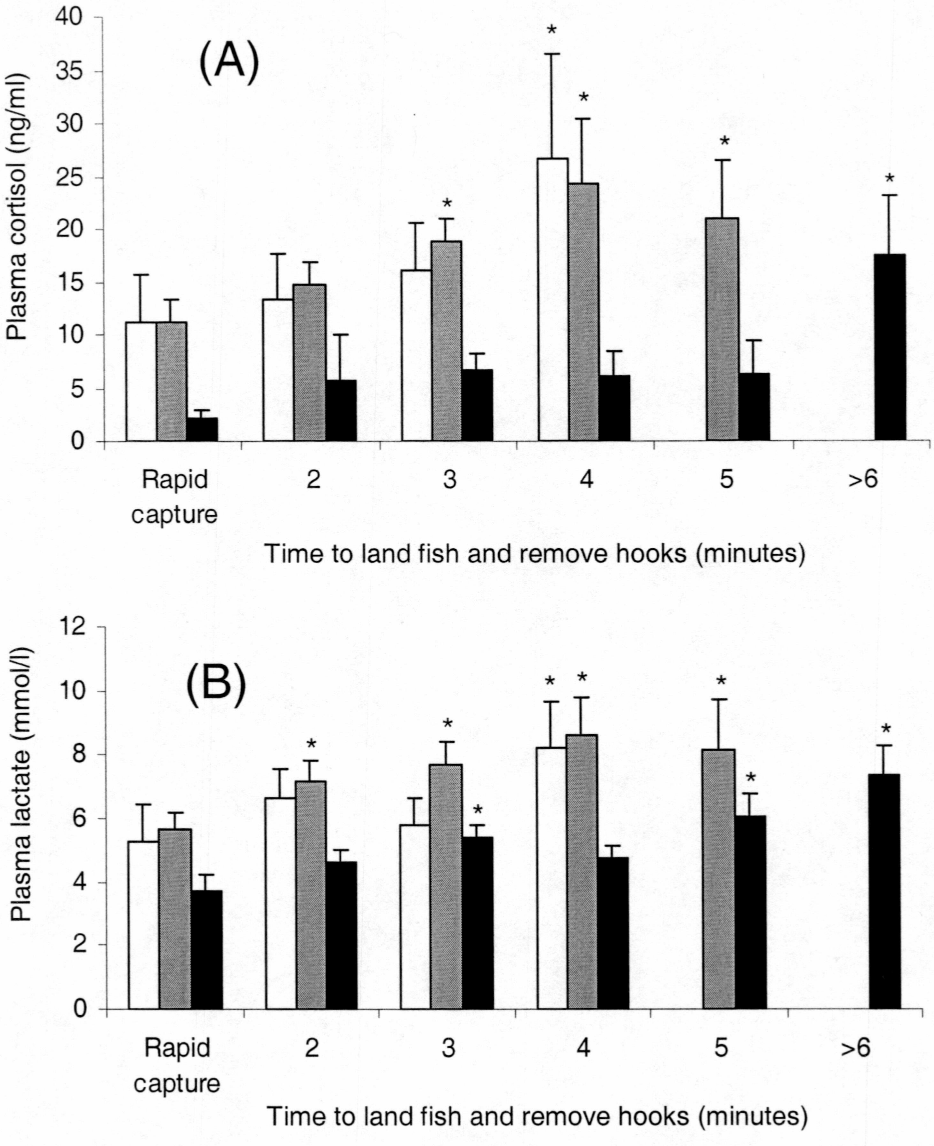

Figure 2.2. Levels of plasma cortisol (A) and lactate (B) in Alagnak River rainbow trout angled and handled during the hook removal process from 2 to greater than 6 minutes. Data are given in means ± SE. Statistically significant elevations of cortisol and lactate about levels in rapid capture fish (trout landed and handled in less than 2 minutes) are indicated by asterisks ($P<0.05$). White bars indicate fish captured in 2000, grey bars represent fish captured in 2001, and black bars indicate fish captured in 2002. Sample sizes are given in Table 2.1.

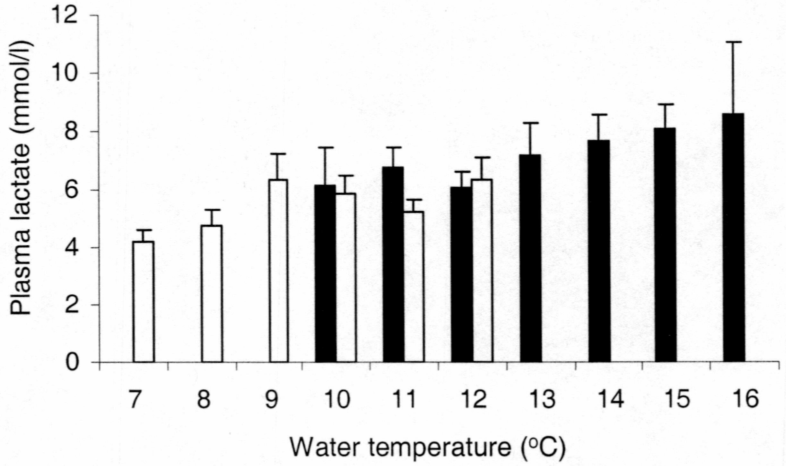

Figure 2.3. Levels of plasma lactate in all Alagnak River rainbow trout captured by angling in 2001 and 2002 by degrees of water temperature (ºC). Data are given in means ± SE. Changes in lactate concentrations were significantly related to temperature ($P<0.05$, ANOVA). Black bars indicate fish captured in 2001 (n=233) and white bars represent fish captured in 2002 (n=104).

Conclusions and Recommendations

I demonstrated that valuable information on the factors influencing the severity of hooking injuries, the duration of capture and handling during hook removal, and the physiological response to angling and handling in wild rainbow trout can be obtained without holding fish after capture. The mortality rates of rainbow trout hooked in different anatomical locations have been extensively researched, leading to estimates of mortality in this study based on the location of observed hooking wounds in Alagnak River rainbow trout. Inference on the peak and duration of plasma cortisol and lactate responses by trout to catch-and-release angling were drawn from numerous studies that have examined the peak physiological response and recovery of rainbow trout from physiological distress.

The results of my study indicate that there are potential benefits of fisheries regulations that minimize hooking injuries in wild rainbow trout subjected to a catch-and-release fishery. For example, a restriction on barbed J hooks would reduce the frequency of hooking injuries and associated bleeding rates, and reduce the amount of time fish are handled when removing hooks. If the management goal is to limit the amount of rainbow trout caught and released, a circle hook only restriction should aid in reducing lethal hooking injuries and make the hooking and landing of fish more challenging and possibly self-limiting. Minimizing the amount of time fish are landed and handled during the angling process will ultimately reduce the peak physiological response and duration of recovery of angled fish. Although these results apply most specifically to the Alagnak

River rainbow trout fishery, they are representative of other popular non-consumptive rainbow trout fisheries in Alaska. As the popularity of angling for wild rainbow trout continues to rise in Alaska, resulting in heavier angling pressure, voluntary and mandated catch-and-release angling practices will inevitably continue to increase. Managers will need to carefully evaluate the potentially cumulative impacts of multiple recaptures on the physiological response by wild fish, consider the importance of the aesthetic value of wild fish to visiting anglers, and focus future research on the prolonged effects of hooking injury and multiple recaptures on trout populations. By minimizing the risk and degree of injury, and initiating angler education programs to include the significance of a short duration of capture, proper removal of hooks, and conservation-minded release techniques, fish survival may be maximized and the aesthetic value of wild fish could be more effectively preserved.

Further research into the long-term effects of non-lethal hooking injuries of Alagnak River rainbow trout would be necessary to evaluate whether fish permanently injured in the eye region or other areas may lose the ability to forage competitively and efficiently, and avoid predators, resulting in growth reduction. There have been numerous complaints made by anglers of poor fishing and lack of trophy-sized Alagnak River rainbow trout compared to previous years when fishing pressure was less intense (J. Meka, personal observation). Rainbow trout in Alaska are known to feed on salmon eggs and carcasses during the salmon spawning months, generally July, August, and September in southwest Alaska (Brink 1995; Eastman 1996). The caloric value of salmon eggs far exceeds any other common rainbow trout food source such as insects and juvenile fish; thus, the foraging ability of trout during months when salmon products constitute the majority of their diet may be an important survival mechanism (Davis et al. 1998). Ultimately, it is necessary to conduct field studies on the feeding rates and growth of rainbow trout subjected to catch-and-release angling and associated hooking injuries to validate if negative effects on trout growth exist. The use of bioenergetic models to estimate the feeding rates of trout with reduced foraging ability from hooking injuries or temporary cessation of feeding resulting from physiological distress may provide insight on the potential effects of angling on Alagnak River rainbow trout growth that may not be evident from other investigations.

Additional sublethal effects resulting from hooking injuries in Alagnak River rainbow trout may involve disease resistance and fish condition. Parasitic copepods of the genus *Salmincola,* most likely *S. californiensis* (Conley and Curtis 1993), were found at the base of the fins, attached to gill filaments, or inside the mouth in 58% of Alagnak River rainbow trout during this study. In general, fish with past hooking injuries had higher incidences of *Salmincola* than fish without injuries. Similar observations have been recorded for rainbow trout in the heavily fished section of the upper Kenai River, Alaska, which have higher rates of past hooking scars and concentrations of *Salmincola* than trout in the less impacted, lower reaches of the river (D. Palmer, USFWS, personal communication). In fish subjected to different types of stress such as capture by angling or recovery from injury, the natural resistance of the fish to parasites may be reduced, which can increase the density of parasite populations (Esch et al. 1975). In heavy infestations (>30 adult female copepods/fish), *Salmincola* sp. can be detrimental to freshwater salmonids in hatchery environments by influencing their respiratory ability due to damage to the gill filaments where individual copepods may attach (Conley and Curtis 1993). It is purportedly rare for heavy concentrations of *Salmincola* to exist in natural fish populations or to have any significant negative impacts on fish health (Conley and Curtis 1993), however, there have been recent complaints made by anglers about the unpleasing appearance of copepod infested fish in some sport fisheries in California (Modin and Veek 2002). Because heavy infections of *Salmincola* and notable damage to the gill filaments of Alagnak River rainbow trout were observed during this study, the apparent increase in copepod frequency in fish with past hooking scars warrants further study into the condition of trout previously captured in the sport fishery.

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